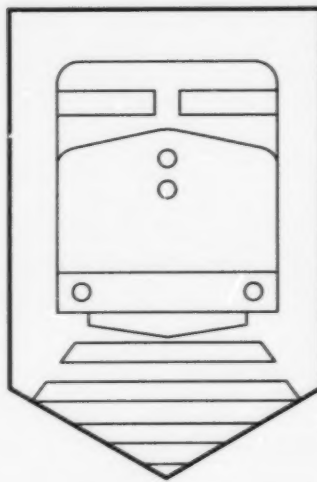
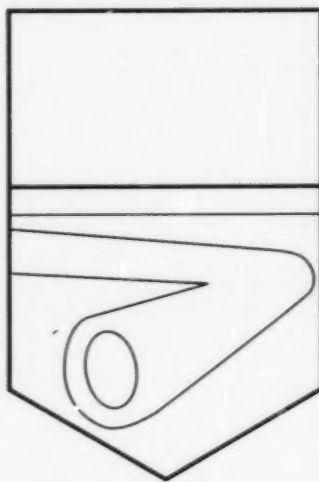
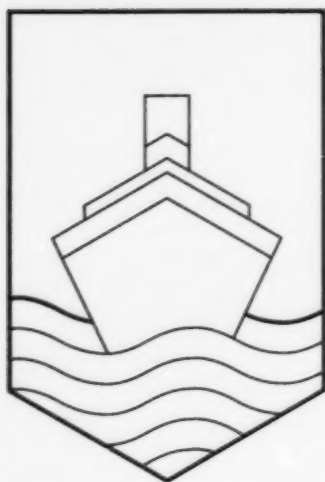


Transportation Safety Board
of Canada



Bureau de la sécurité des transports
du Canada



AVIATION OCCURRENCE REPORT

**HYDRA MANAGEMENT LTD.
AEROSPATIALE 332C SUPER PUMA C-GQRL
QUATAM RIVER, BRITISH COLUMBIA
03 OCTOBER 1987**

REPORT NUMBER 87-P70086

Canada

The Transportation Safety Board of Canada (TSB) investigated this occurrence for the purpose of advancing transportation safety. It is not the function of the Board to assign fault or determine civil or criminal liability.

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SYNOPSIS

The helicopter had lifted a log and had begun to move forward when the main gearbox flexible mounting plate failed. This caused the Bendix drive shafts to fail, interrupting the transmission of engine power to the rotor system. The pilot jettisoned the log, but was unable to enter autorotation. The helicopter fell to the mountainside and was destroyed by impact and fire; the pilot and co-pilot were fatally injured.

The Transportation Safety Board of Canada determined that the flexible mounting plate failed in fatigue because the true number of high-load cycles applied to the plate during heli-logging operations were not taken into account in the manufacturer's determination of the service life of the plate. The operator did not detect cracks in the flexible mounting plate during inspections the night before and morning of the accident.

13 April 1991

Ce rapport est également disponible en français.

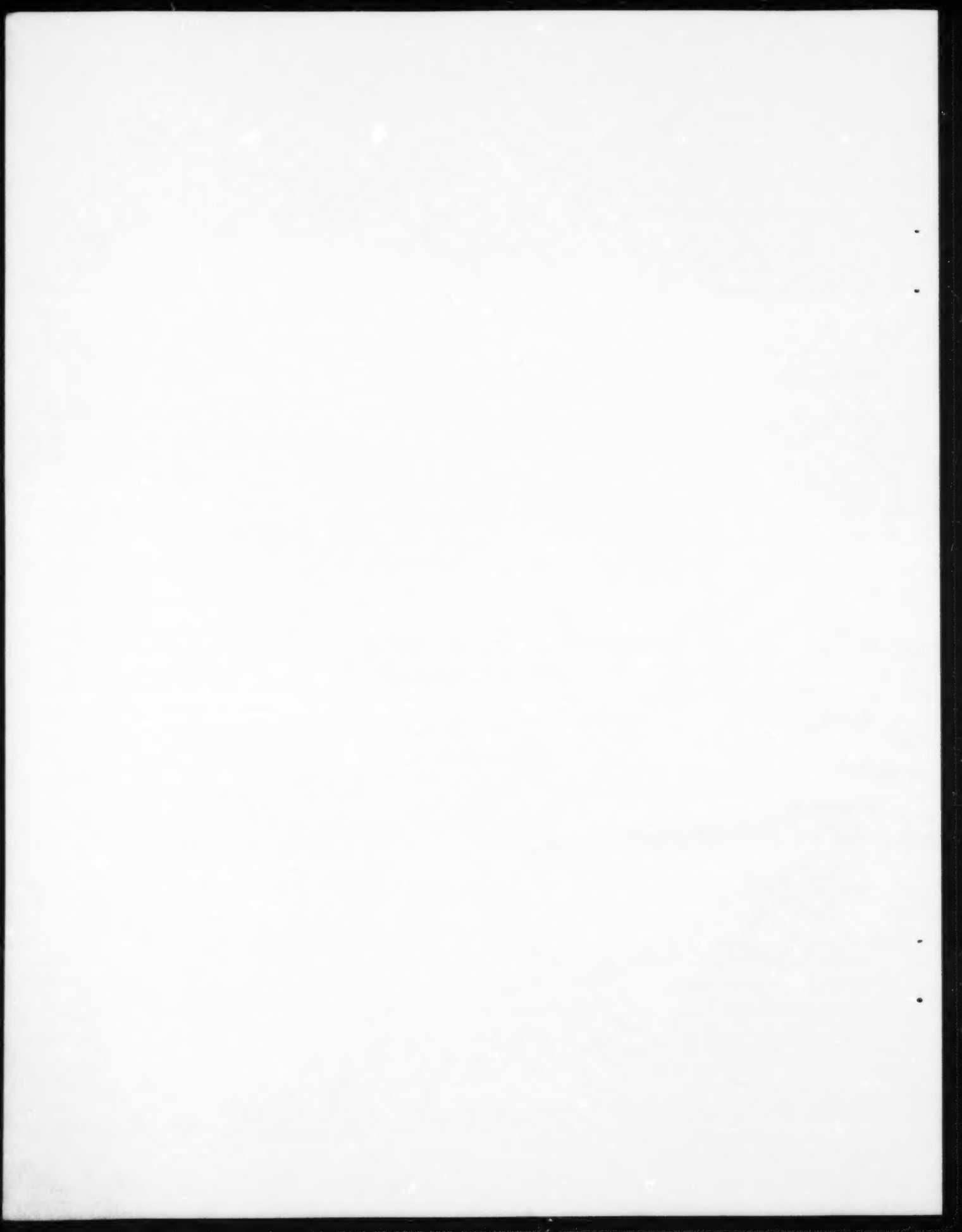


TABLE OF CONTENTS

	Page
1.0 FACTUAL INFORMATION	1
1.1 History of the Flight	1
1.2 Injuries to Persons	2
1.3 Damage to Aircraft	2
1.4 Other Damage	2
1.5 Personnel Information	2
1.6 Aircraft Information	3
1.6.1 Weight and Balance	3
1.6.2 Flexible Mounting Plate Description and Limitations	4
1.6.3 Operator's Progressive Inspection Program	5
1.7 Meteorological Information	6
1.8 Aids to Navigation	6
1.9 Communications	7
1.10 Aerodrome Information	7
1.11 Flight Recorders	7
1.12 Wreckage and Impact Information	7
1.13 Medical Information	7
1.14 Fire	8
1.15 Survival Aspects	8
1.16 Tests and Research	8
1.16.1 Laboratory Analysis - Failure Mode	8
1.16.2 Flexible Mounting Plate Inspection	9
1.16.3 Forces Acting on the Flexible Mounting Plate	10
1.16.4 Cycle Count	11
1.16.5 Autorotation	12
1.17 Additional Information	12
1.17.1 History of Flexible Mounting Plate Failures	12
1.17.2 The McAllister Hook	13
1.17.3 Subsequent Studies and Actions	13
 2.0 ANALYSIS	 15
2.1 Introduction	15
2.2 Cycle Definition and Application	15
2.3 Flexible Mounting Plate Forces During a "Turn" ..	15
2.4 Flexible Mounting Plate Failure	16
2.5 Flexible Mounting Plate Inspection	17
2.5.1 Cycles/Inspection Relationship	17
2.5.2 Inspection and Maintenance	17
2.6 Autorotation	18

TABLE OF CONTENTS

		Page
3.0	CONCLUSIONS	19
3.1	Findings	19
3.2	Causes	20
4.0	SAFETY ACTION	21
4.1	Action Taken	21
4.2	Further Action Required	21
4.2.1	Designed Life of the Flexible Mounting Plate	21
4.2.2	Flexible Mounting Plate Inspection	22
5.0	APPENDICES	
	APPENDIX A WEIGHT AND BALANCE CONDITION	A-1
	APPENDIX B MGB ATTACHMENT AND SUSPENSION	B-1
	APPENDIX C AS 332 TITANIUM FLEXIBLE MOUNTING PLATE	C-1
	APPENDIX D EXCERPT - MASTER SERVICING RECOMMENDATIONS	D-1
	APPENDIX E ENGINE SCHEMATIC DIAGRAM	E-1
	APPENDIX F FLEXIBLE MOUNTING PLATE - NEW BLADE GEOMETRY	F-1
	APPENDIX G1 FLEXIBLE MOUNTING PLATE - SUPER PUMA C-GQRL	G-1
	APPENDIX G2 COMPARISON OF MGB/ENGINE ALIGNMENT	G-2
	APPENDIX H FLEXIBLE MOUNTING PLATE BLADE FAILURES C-GQRL	H-1
	APPENDIX J LIST OF LABORATORY REPORTS	J-1
	APPENDIX K GLOSSARY	K-1

1.0

FACTUAL INFORMATION

1.1

History of the Flight

The Aerospatiale Super Puma, C-GQRL, had been flown with a two-man crew (pilot and co-pilot) since it began heli-logging in early July 1987. The pilot flew the helicopter from the left seat and visually positioned the 150-foot long-line hook by leaning to his left and looking down through a Plexiglas bubble in the door. The co-pilot's function was to monitor the cockpit instrumentation to ensure that applicable performance and airframe limits were not exceeded. The co-pilot also recorded the weight of each sling-load as it was lifted and maintained a cumulative record of the lift cycles.

On 03 October 1987, the Super Puma departed the base camp at 0806 Pacific daylight time (PDT)*. The aircraft carried one hour's fuel; it was hot-refuelled at the end of each hour and each time the two pilots exchanged seats. Three sequences were completed with the original crew, then a new pilot, approved by the company as co-pilot only, replaced one of the pilots and occupied the right seat. The intention was for the original, qualified pilot to fly another two sequences in the left seat and then to shut down the helicopter for a half-hour.

The helicopter had moved 22, 26 and 30 logs during the three sequences, respectively. The fourth sequence was uneventful, and an unknown number of logs were moved before the helicopter was landed for fuel. During the fifth sequence, at approximately 1255 PDT, the helicopter had lifted a log, turned downhill, and began to move forward when the following sequence of events happened in rapid succession: a "twang" was heard, followed by an explosion and a fire in the engine and main gearbox (MGB)** area; the pilot jettisoned the log; another explosion was heard; the main rotor blade rpm decreased rapidly; and the helicopter fell to the mountainside and burned. Witnesses estimate that this sequence of events took seven seconds.

- * All times are PDT (Coordinated Universal Time (UTC) minus seven hours) unless otherwise stated.
- ** See Glossary for all abbreviations and acronyms.

The accident occurred during the hours of daylight at lat 50°19'N, long 124°51'W, at 1,000 feet above sea level (asl), in mountainous terrain on the British Columbia mainland, 27 miles northeast of Campbell River. Both the pilot and the co-pilot were fatally injured in the accident.

1.2 Injuries to Persons

	Crew	Passengers	Others	Total
Fatal	2	-	-	2
Serious	-	-	-	-
Minor/None	-	-	-	-
Totals	2	-	-	2

1.3 Damage to Aircraft

The helicopter was destroyed by the impact and fire.

1.4 Other Damage

A forest fire was started by the crash and destroyed a large stand of timber on the mountainside.

1.5 Personnel Information

	Pilot-in-Command	Co-pilot
Age	38	43
Pilot Licence	Commercial Helicopter	Commercial Helicopter
Medical Expiry Date	Valid	Valid
Total Flying Time	5,515 hr	3,320 hr
Total on Type	290 hr	695 hr
Total Last 90 Days	290 hr	290 hr
Total on Type Last 90 Days	290 hr	240 hr
Hours on Duty		
Prior to Occurrence	5 hr	2 hr
Hours off Duty		
Prior to Work Period	12 hr	14 hr

1.6 Aircraft Information

Manufacturer	Aerospatiale
Type	AS 332C (Super Puma)
Year of Manufacture	1981
Serial Number	2012
Certificate of Airworthiness	Valid
Total Airframe Time	2,405 hr
Engine Type (2)	Turbomeca Makila 1A
Rotor Type	Aerospatiale, fully articulated 4 bladed
Maximum Allowable	
Take-off Weight	18,410 lb
With External Load	20,615 lb
Recommended Fuel Types	JP1, JP4, JP8

The aircraft was certified, but whether it was maintained in accordance with existing regulations and approved procedures is not clear. This issue is discussed later in the report. The company had a qualified aircraft maintenance engineer (AME) and two apprentice AMEs on site. A progressive inspection (PI) program was in force and was based on a 400-hour cycle. The operator stated that, in addition to the requirements of the PI, daily inspections that included a thorough washing of the MGB deck area were conducted; and that morning and evening inspections were conducted on the flexible mounting plate (FMP) for cracking of the leaves (blades). Maintenance was carried out at the end of daily flying operations and was normally concluded during the night.

An apprentice AME stated that he completed a wash-down and general inspection of the transmission deck area, including the FMP, the night before the accident. He stated that he did not initiate a specific check for cracks in the FMP assembly, but said that he did not notice any cracks during his inspection. Illumination for maintenance work was provided by an overhead yard-light, a hand-held fluorescent tube-type light, and flashlights.

There was no evidence recorded during the initial investigation regarding whether the licensed AME, who was also the operator, inspected the FMP for cracks the night before and/or the morning of the accident. The operator has subsequently indicated, in submissions to the Investigator-in-charge and in legal depositions, that he did complete the aforementioned inspections.

1.6.1 Weight and Balance

To permit maximum lift capability, the helicopter's weight was reduced by stripping out non-essential,

non-structural components. It was determined that, at the time of the accident, the weight-and-balance condition was within the prescribed limits. (See Appendix A.)

1.6.2 Flexible Mounting Plate Description and Limitations

The helicopter MGB and main rotor head are supported by three bars attached to the top of the MGB casing, just below the main rotor head. (See Appendix B.) The bottom of the MGB is stabilized through attachment to the centre of a titanium, S-shaped, horizontal FMP, which in turn is attached to the helicopter fuselage at the right-forward and left-rear corners. The left-forward and right-rear corners are unsecured and move in conjunction with MGB movement. There is a nine millimetre clearance between the bottom of the FMP and the top of the engine/MGB deck. Slots in the FMP create six blades (also called "foils" or "leaves")* on the forward section and eight blades on the rear section (see Appendix C). The blades are aligned with the lateral axis of the aircraft. The attachment flange for the blades forward of the transmission is attached to the deck at an angle of 53 degrees to the axis; the flange for the blades aft of the transmission is attached at 90 degrees. Blade alignment prevents any lateral displacement of the transmission while allowing limited longitudinal displacement.

Aerospatiale had given the FMP an operational service life of 2,000 hours or 8,000 cycles, whichever occurred first. A flight hours/cycles relationship of one flight hour equating to four cycles was used to provide operators a standard for converting component life from an "hours" basis to a "cycles" basis. For the helicopter logging mission, it was deemed more appropriate to establish the life of certain helicopter components on the number of cycles accumulated, than to measure component life in terms of flight hours only.

It specified to an operator, who was intending to commence logging, the basis on which to convert existing helicopter flight hours to cycles. Once the helicopter commenced logging operations, cycles were counted as described in section 1.16.4.

* This report identifies the front blades by numbers one through six beginning at the front, in accordance with the nomenclature used in the TSB Laboratory reports. These numbers correspond to the manufacturer's numbers nine through 14 respectively. (See Appendix C.)

The service-life criteria were deemed to be valid by the manufacturer provided that a visual inspection for cracks in the plate was performed every 40 hours after either: the first 1,000 hours of flying time; or the accumulation of the first 4,000 cycles. The requirement to inspect the plate at 4,000 cycles, if that "half-life" criterion was reached first, was in force at the time of the Hydra accident. This cycle consideration was added as a result of the realization that plate failures in the logging role were more as a result of low-cycle fatigue rather than high-cycle fatigue.

This 40-hour inspection cycle had been established by Aerospatiale as a result of blade cracking that had been detected in the FMPs of other Super Pumas, prior to this accident. The 40-hour frequency is based upon Aerospatiale's results from laboratory fatigue tests, instrumented flight tests, and mathematical (damage tolerance) calculations. The inspection is published under Section 5.99 of the "Limitations de Navigabilité" for the AS 332 Super Puma by the "Direction Générale de l'Aviation Civile" (DGAC), dated 20 May 1987, and is detailed in the manufacturer's Master Servicing Recommendations (MSR) 5.22 and Work Card 63.30.00.601 (WC 63.30). (See Appendix D.)

In establishing the 40-hour check, the manufacturer based the calculations on the assumption that 15 cycles per flight hour was the appropriate relationship to use for the logging mission. The tests and calculations indicated that not more than two blades would fail in a 40-hour period, and more than two blades must be cracked before the plate would fail. Therefore, by requiring FMP inspections to be performed every 40 hours, any significant cracking would be detected before plate failure could occur.

1.6.3 Operator's Progressive Inspection Program

The 400-hour PI program had been prepared by the operator and submitted to the helicopter manufacturer for review. The latter informed Transport Canada (TC) that the document was equal to or better than the requirements contained in the MSR. TC forwarded that information to the operator with approval to incorporate that procedure. The 400-hour PI program, however, did not reflect the required 40-hour periodicity for the FMP crack inspection, and the PI program does not take precedence over the requirements of Section 5.99 of the manufacturer's "Limitations de Navigabilité".

The operator's PI program called for WC 63.30 to be completed only once during the 400-hour cycle, at the 150-160 hour period. WC 63.30 is the inspection that details looking for FMP cracks in the FMP blades. That inspection is not called up again in the Operator's PI program until the same point during the next 400-hour cycle, specifically, 400 hours later. The operator's PI records bear this out; they show that the last recorded inspection as per WC 63.30 was carried out at the 150-hour point of the first PI program. The operator had completed the first 400-hour PI program and the helicopter was at the 70-hour point in the second, repeat PI program when the accident occurred. Therefore, the last recorded inspection of the FMP as per WC 63.30 occurred at 2,087.7 airframe hours, two months and 311.3 flight hours before the accident.

The operator stated that because of his concern about the FMP, he improved on the 40-hour inspection requirement by completing it daily. He stated that this daily FMP inspection was not logged because it was not required to be logged. He has also subsequently stated that an error in the numbering of the PI work cards had gone undetected, and that WC 63.30 and Work Card 63.20.00.601 (WC 63.20) were mistakenly transposed in the preparation of the PI.

WC 63.20 requires checking of the torque on the bolts which attach the bottom of the transmission to the centre of the FMP and is performed from inside the helicopter cabin through a hole in the cabin roof.

It is the operator's contention, therefore, that the inspection shown in the PI as 63.20 and being required every 30 hours, should have been 63.30 and not 63.20 as written. It is noted, however, that the MSR does require 63.20 to be completed every "20 to 30 hours" and the WC 63.20 shown in the PI appears to be correctly called for.

1.7 Meteorological Information

The weather at the time of the accident was good. The visibility was more than 20 miles, and the sky was clear. The wind was light, from a southwesterly direction.

1.8 Aids to Navigation

Not applicable.

1.9 Communications

The pilots and the logging crew were able to contact each other on very high frequency radios. Immediately prior to and during the accident sequence, there were no radio transmissions from the helicopter pilots.

1.10 Aerodrome Information

Not applicable.

1.11 Flight Recorders

The aircraft was not equipped with a flight data recorder (FDR) or a cockpit voice recorder (CVR), nor was either required by regulation.

1.12 Wreckage and Impact Information

The accident occurred on the side of a 45-degree mountain slope. The helicopter fell to the mountainside while maintaining a southerly heading and came to rest approximately 300 feet below the pick-up. It crashed onto a large tree stump and burned. After the fire subsided, the only recognizable components were the two engines, main rotorhead, MGB, and the tail-rotor drive shafts. The four main rotor blades, although severely fire-damaged, did not reveal any evidence of rotational impact damage. The five tail-rotor blades had been consumed by fire; the remaining components of the tail-rotor anti-torque system displayed no pre-existing unserviceabilities. The MGB casing was badly burnt; however, the gear train was still intact and appeared to have been serviceable at impact. Both engines had split open at the turbine sections. (See Appendix E.) The two free-turbine wheels from the number one (left) engine were found 50 feet and 600 feet respectively, below the crash site; the free-turbine section from the number two (right) engine was damaged, but all components were present.

1.13 Medical Information

There was no evidence that incapacitation, physiological or psychological factors affected the crew's performance.

1.14 Fire

Witnesses reported that the engine and MGB area was engulfed in flames as the helicopter fell to the mountainside. About 75 per cent of the helicopter was consumed after impact by the intense, fuel-fed fire.

1.15 Survival Aspects

The accident was not survivable. Medical reports indicate that deceleration forces were beyond the limits of normal human tolerance. Although a shoulder harness was available to the pilot, it was not normally worn because it restricted his left-lateral movement and, thus, his ability to adequately see the sling-load and the ground directly below the helicopter. The co-pilot's seat belt had become unfastened during the accident and was badly burned. It could not be determined whether he was wearing his shoulder harness.

1.16 Tests and Research

The engines, MGB, and tail section were recovered and sent to the TSB Engineering Laboratory for examination. All cockpit warning lights, gauges, and power controls were destroyed by fire and were, therefore, not available for analysis. All TSB Engineering Reports are listed in Appendix J.

1.16.1 Laboratory Analysis - Failure Mode

The initiating event in this accident was the total failure of all six blades of the MGB FMP at the forward attachment point. (See Appendix G1.) Failure of the FMP, while in tension during the last lifting operation and as the helicopter moved forward, caused a lateral misalignment between the engines and the MGB and rotor assembly. (See Appendix G2.) The engine-to-MGB liaison tubes separated at the aft attachments, allowing the Bendix drive shafts to come into contact with their respective housings. The friction created by this contact caused sufficiently high temperatures to cause torsional overload of a welded joint on the flexible diaphragms of each drive shaft. The right Bendix drive shaft failed first, instantly unloading the right engine free turbine which then oversped and triggered the automatic shutdown of the engine via the overspeed governor.

As the right engine decelerated, the left Bendix drive shaft failed. This in turn unloaded the left engine free turbine, allowing it to also overspeed. The left

engine did not shut down because, in this dual-engined configuration, the free turbine overspeed safety system inhibited the second engine and prevented its automatic shutdown, once the first engine had failed. Consequently, the left engine continued to overspeed until the first-stage power turbine rotor burst because of centrifugal overload.

The TSB Engineering Laboratory found fatigue cracking in five of the six blades in the forward section of the FMP. Because of fretting, high temperature oxidation, and molten metal deposits on the fracture surfaces, the exact fatigue mode and crack propagation rates could not be determined. However, the macroscopic crack surface features indicated both the extent and general nature of fatigue cracking in each of the blades. The initial stages of fatigue in all blades were characterized by a relatively smooth textured surface representative of a slow growth mode. In four of the five blades, identified as numbers one, two, four, and five, these zones gave way to a more roughly textured surface typical of more rapid fatigue. Slant fractures and distinct shear lips defined the onset of the final overload separation. Measurements of these features indicated that, in three of the blades, fatigue cracking in excess of 80 per cent of the cross-sectional area had occurred prior to overload failure, and in blade number three, fatigue had occurred in excess of 90 per cent of the blade cross-section. (See Appendix H.) The aft-most blade of the forward attachment area, number six, had failed in overload with no evidence of fatigue.

The TSB Laboratory report concluded that, at the time of the visual inspection the night before the accident, at least blade number three was cracked through to the upper surface of the plate, and that blades numbers two and four could also have been cracked through to their upper surfaces.

The composition and heat treatment condition of the FMP was found to be in accordance with the manufacturer's specifications.

1.16.2 Flexible Mounting Plate Inspection

The aircraft maintenance manual does not require special inspection of the FMP until that component reaches its half-life. Then the radii of the blades at the fore and aft attachment points are to be inspected following each 40-hour flight period.

This inspection is a visual examination of the general external appearance of the plate, to include distortion, breakage, cracks, scores, corrosion, and signs of overheating and wear.

An opening behind the right engine firewall on the forward right side of the main rotor shaft is the only area through which the forward section of the FMP can be inspected. The plate is located approximately two feet below the top of the engine firewall and is surrounded by high pressure lines and hydraulic pumps that permit visual inspection of blades one to four only. The critical areas of blades five and six cannot be seen from the top. On C-GQRL, fatigue cracking initiated from the forward, lower corners of the blades near the point of attachment to the helicopter fuselage. The limited space between the plate and the fuselage, and the requirement to examine the plate from above render inspection of the fatigue crack initiation sites difficult.

The profile of the cracks, as evidenced by the crack arrest markings, indicate that the initial corner cracks should have been visible on the forward faces of the blades in the early stages of formation. These cracks would have penetrated through to the top surface of the blades, once they had progressed through 25 to 30 per cent of the blade cross-sections. They should have been visible from the inspection point, above, albeit with some difficulty.

The inspection procedure per WC 63.30 (See Appendix D.) states, in part:

Crack detect the hatched areas shown in detail H. Any crack detect requires the flexible mounting plate to be removed and discarded.

Detail H (See Appendix D.) clearly illustrates, via hatching, the specific areas to be examined; however, the illustration features hatched areas on the upper surface only and, thereby, neglects the critical bottom surface.

1.16.3 Forces Acting on the Flexible Mounting Plate

The forces acting on the FMP are as follows:

-Tensile loads along the blades caused by application of torque. This load causes little displacement but significant stresses in the blades. The frequency of variation of this stress is the origin of the cracks in the blades.

-Forward/rearward loads in the mounting plate caused by filtration of vibrations from the rotor head or from tilting of the rotor. These loads cause significant displacement but weak stresses. They may, nevertheless, be involved in the growth of cracks already initiated.

-Loads perpendicular to the plane of the mounting plate. In flight, these forces are virtually zero, as all the stress is taken up by the MGB bars. On the ground, these loads are weak and directed downwards, are due to play in the take-up of the weight of the rotor head and are negligible.

1.16.4 Cycle Count

The manufacturer defined a "cycle" in the MSR, Chapter 5.15 (Time Limits), under IMPORTANT NOTE as follows:

1.3.2 Sling Load Operation

When the aircraft is used in that configuration a cycle is equal to carrying an external load

The operator counted each actual log-lift operation as a cycle. He also separately recorded helicopter/log hook-ups where log-lifts were aborted or log repositioning occurred without the log being lifted clear of the ground. The operator stated that he kept a record of these aborts and repositionings because it was his interpretation that this partial-cycle operation could have an effect on the component. The FMP in C-GQRL failed 475 flight hours after installation. The total plate cycle count at the time of failure was 7,661 cycles, plus the unknown number of cycles accrued by the crew slinging logs in the final two hours, plus 405 log aborts or repositionings.

The aircraft Journey Log had an error in the cycle computations, an error only discovered late in the accident investigation. An arithmetical addition error by the operator resulted in his totals being 180 cycles below the actual number. This cycle-count shortage did not result in the operator overflying the 8,000 cycle life limit at the time of plate failure. The operator was anticipating reaching the 8,000-cycle limit at the end of the day of the accident, or soon thereafter.

The record of cycles was kept by the co-pilot; consequently, the figures for the last two flight hours were destroyed in the fire.

In heli-logging, a "turn" represents the complete helicopter sequence of lifting a log, transporting it down the mountainside, dropping it into the water, flying back up the mountainside, and repositioning in the hover for the next lift. The average time for the crew of C-GQRL to complete a turn was three minutes. The pilot used a descent rate of 2,000 to 3,000 fpm down the mountainside; he decelerated and arrested the helicopter descent before dropping the log, and then climbed the helicopter back up the mountainside as rapidly as possible. One cycle was counted for each turn.

1.16.5 Autorotation

Following this accident, the manufacturer conducted simulator tests to determine the effect of losing both engines under maximum torque conditions. It was determined that, when the engines failed, the pilot had only 1.5 seconds to jettison the load, lower the collective lever, and put the helicopter in a 30-degree, nose-down attitude. If these parameters were not achieved, it was determined that successful autorotation would not be possible. The tests also indicated that if the load was jettisoned one second after both engines failed, and the collective lever was not lowered, the main rotor rpm would decay to 38 per cent (100 rpm) of the normal operating speed within three seconds of the dual engine failure.

The main rotor system includes four carbon-composite blades each weighing 185 pounds. At a normal rotational speed of 265 rpm, the rotational inertia forces are relatively low and allow the rotor speed to rapidly decay if engine power is lost at high collective-pitch settings.

1.17 Additional Information

1.17.1 History of Flexible Mounting Plate Failures

Twelve cases of FMP failures have been identified; 10 involved plates that had been used in heli-logging operations, and two that had never been used for heli-logging. All of the failures have occurred at the forward attachment point; however, in none of the previous failures had all the blades failed and resulted in an accident. Nine of the previous plate failures were found during a visual inspection of the plate area when only one or two of the blades had cracked or failed. One failure was detected during a visual inspection after the pilots had reported unusual in-flight vibrations. Another failure was found when

the FMP had reached its life limit and was being replaced. In all cases, the fatigue cracks originated from the underside of the plate at the blade/slot radii, near the plate/fuselage forward attachment points. There have been no recorded failures of the blades on the rear portion of the FMP.

1.17.2 The McAllister Hook

The helicopter was fitted with a McAllister hook and a weight (load) cell that automatically weighs the logs as they are lifted. The McAllister hook is a closed hydraulic system that dampens load oscillations and prevents a broken line from being catapulted up into the main rotor. The weight cell operates independently from the McAllister Hook and has an accuracy of plus or minus 0.25 per cent. The system allows the helicopter crew to instantly assess the weight of the load as the strain is taken on the sling and to reject a load that approaches the maximum allowable external weight before the overall helicopter maximum gross weight is exceeded.

1.17.3 Subsequent Studies and Actions

In early 1988 (after this accident), Aerospatiale attached strain gauges to a FMP and installed the test plate on a Super Puma. The aircraft was then flown under normal heli-logging conditions, and the strain data were recorded. Analysis of that data by Aerospatiale engineers produced the following results:

1. The torque load ranged twice between zero and maximum during each logging cycle (turn):
 - descent: maximum torque with the log on liftoff, then zero torque during the descent;
 - climb: maximum torque to climb after log release, then zero torque during the transition to hover.
2. The stress levels measured on the mounting plate blades account for blade damage due primarily to low-cycle fatigue.
3. Two such cycles (directly related to the torque variation cycles) occur during each log transport. Log-positioning manoeuvres involve relatively minor power variations around the hover power level, and are not significant.
4. The forward mounting plate blades are subjected to the most critical fatigue loads.

At the time of the accident, Aerospatiale was working on a new design for the FMP that features new blade geometry. (See Appendix F.) The plate was to be made available in 1988.

The manufacturer has stated that the new-geometry FMP was being researched because of the manufacturer's desire for improved FMP reliability, and not because of a recognition of any flight safety concern. The manufacturer has stated that they were content that the mandatory inspections would uncover any FMP cracks before any cracked-plate situation became dangerous.

This re-designed plate has now been designated as a mandatory installation for Super Puma helicopters involved in heli-logging operations.

2.0

ANALYSIS

2.1

Introduction

The failure of the FMP has been identified as the initiating event in this accident. The helicopter operator, using the accepted manufacturer's definition for cycle count, recorded each log move so that an accurate cycle count would be maintained. In that manner, the operator could adhere to the published cycle limits for all "lifed" items, including the FMP.

As previously stated, the FMP component life limit of 8,000 cycles had not quite been reached at the time of the accident.

There is, however, clear indication that the definition of what constitutes a cycle is inappropriate. Also, questions have been raised about the operator's PI program and whether the manufacturer's inspection requirements for the FMP were being met. Therefore, this analysis concentrates on the cycle concept and its application to heli-logging operations, and on the inspection requirements for the FMP. The analysis also considers why an autorotation was not accomplished.

2.2

Cycle Definition and Application

The failure of the FMP near the specified cycle life limit, but at only 475 flight hours, indicates the absolute importance for the helicopter in the logging mission of measuring the life of the component in terms of the number of accumulated cycles and not flight hours. Further, the number of cycles accumulated per flight hour can vary significantly depending on the nature of the geographical location and the distance between pick-up and drop locations. A simple correlation between flying time and cycles is, therefore, difficult to assess. It then becomes evident that the life span of the FMP must be specified in terms of the number of cyclical applications of significant torque, and not in terms of the number of flight hours.

2.3

Flexible Mounting Plate Forces During a "Turn"

Heli-logging operations on the west coast of Canada probably incur the most extreme helicopter stresses experienced anywhere in the world; this is because of the size of the individual logs and the extremes in vertical climbs and descents for the helicopter along

the sides of the mountains between log pick-up and drop-off. As described in sections 1.16.3 and 1.17.3, the significant forces applied to the FMP were those associated with the maximum variations in the torque applied, via pilot collective-lever input. The log pick-up required maximum or near-maximum permissible torque. Descent down the mountainside at 2,000 to 3,000 fpm towards the drop area involved near-autorotation at minimum torque levels. Following log release, the pilot climbed the helicopter rapidly back up to the pick-up area by again applying maximum engine power (torque) via the collective control, and then reducing the torque to near minimum again as he approached the hover above the next lift site.

During a "turn", the rotor transmission and, through the mounting arrangement, the FMP were subjected to two distinct applications of maximum-to-minimum variations of torque. It is these extreme variations, or cycles, in torque that are the stresses that should constitute the "cycles" to be counted in determining the life of the FMP. During each sling load, or "turn", there were at least two distinct cycles experienced; but the manufacturer only required one cycle to be counted toward the service life of the FMP component.

Heli-logging operations can subject the FMP to repeated, extreme changes in loads during one "turn" and can, therefore, incur more than one cycle per "turn". It is the Board's opinion that, for the purpose of determining FMP life in heli-logging operations, Aerospatiale's definition of what constitutes a cycle is inappropriate.

2.4

Flexible Mounting Plate Failure

The manufacturer's definition of a cycle did not accurately account for stresses encountered in logging operations and, consequently, did not accurately define the life limit of the FMP. Since at least two cycles were applied to the FMP per "turn", the cycle count at which the failure occurred was, in reality, at least twice the actual number recorded and, therefore, almost double the number of cycles specified as the life limit.

The FMP failed, therefore, well beyond the 8,000 cycle life limit. It only appeared to fail near the specified limit because of the inappropriate definition of what constitutes a cycle.

2.5 Flexible Mounting Plate Inspection

2.5.1 Cycles/Inspection Relationship

The manufacturer had instituted a requirement for the FMP to be visually inspected for integrity, every 40 hours after the plate had reached half-life. Prior to this accident, all but two FMP failures had been detected by visual inspection on the respective aircraft. The other two were discovered cracked after they had been removed from the helicopters for other reasons. The TSB Engineering Laboratory determined that at least one and possibly three blades of the Hydra FMP were cracked through to the upper surface when it was reportedly inspected the night before and morning of the accident. The crack or cracks was or were not detected during the inspections, which the operator states were conducted twice daily.

The background as to how the manufacturer established the 40-hour FMP inspection has been explained. Cycles were, however, being accumulated on C-GQRL much more rapidly than anticipated by the manufacturer.

If, for example, the manufacturer had expressed the inspection interval based upon a number of cycles, the 40-hour inspection would equate to: 40 hours multiplied by the assumption of 15 cycles per hour, equaling 600 cycles. Since the Hydra operation averaged 20 "turns" per hour, and it has been shown that each "turn" generated at least two cycles, the FMP was exposed to an average of 40 cycles per hour. If the manufacturer had, therefore, specified the inspection to be completed every 600 cycles, that would represent a flight time of: 600 cycles divided by 40 cycles per hour, equaling every 15 hours. Put in other words, using this higher cycle application rate of 40 cycles per hour, the expected damage tolerance rate would be: not more than two blade failures in a 15-hour period.

The operator's sworn statement that he was inspecting the FMP on a daily basis, notwithstanding the lack of a requirement to do so in his PI program, meant that the FMP was being inspected at a frequency less than every 15 hours. No cracks were discovered the night before and the morning of the accident flight.

2.5.2 Inspection and Maintenance

The operator's daily inspection of the FMP for cracks was not documented in the company's maintenance records. The only recorded inspection of the FMP for cracks, as delineated in WC 63.30, is the one carried out at 2087.7 airframe hours, 311 flight hours before the accident occurred.

The FMP inspections which the operator has testified were done the night before and morning of the accident did not reveal FMP cracks which engineering analysis indicates were present.

2.6 Autorotation

During heavy lift operations, the helicopter's rotor blade pitch-angles are high, producing maximum lift and consequently, maximum drag. In the Super Puma, the lightweight carbon composite rotor blades, turning at 265 rpm, comprise a relatively low-inertia rotor system. Consequently, when engine power was lost, the low rotor inertia in conjunction with the high blade drag resulted in a rapid decay of main rotor rpm. It has been determined by Aerospatiale that the pilot had only 1.5 seconds available to analyse the malfunction and take the necessary actions to enter autorotation. It is unlikely that the pilot could have detected, analysed, and reacted to the complex nature of the problem in the time available.

3.0

CONCLUSIONS

3.1

Findings

1. The main gearbox flexible mounting plate (FMP) failed in fatigue, just after the helicopter had picked up a heavy sling load.
2. The failure of the FMP permitted the gearbox to rotate, thus misaligning the drive shafts from both engines to the main gearbox. The misalignment created contact between the drive shafts and the engine-to-gearbox liaison tubes, and the drive shafts failed.
3. The right engine drive shaft failed first, causing the engine to unload, overspeed, and then shut down automatically when the overspeed protection circuit cut in. When the left engine drive shaft failed immediately after, the engine unloaded but oversped because of a circuit which does not allow the remaining engine to be shut down. The left engine failed because of centrifugal overload of the first-stage power turbine rotor.
4. When the power loss occurred, the main rotor rpm decayed rapidly as a result of the low rotor inertia and high blade drag.
5. Fire broke out in the main gearbox area before the helicopter fell to the ground.
6. The pilot did not have sufficient time to enter autorotation.
7. The manufacturer's definition of what constitutes a cycle does not accurately account for the significant stresses that are applied to the FMP during heli-logging operations.
8. The nature and extent of the fatigue cracking indicated that at least one and possibly three blades were cracked through to the upper surface of the FMP when it was reportedly inspected the night before and the morning of the accident.
9. The FMP was required to be inspected for cracks every 40 hours; the operator's approved PI schedule calls for this inspection only once every 400 hours, at the 150-hour point of the 400-hour maintenance cycle.

10. The operator's PI schedule, which did not contain the mandatory 40-hour periodicity for the FPM crack inspection, was passed to the manufacturer and TC for concurrence and then approval, respectively.
11. The aircraft records reveal that the last recorded FMP crack inspection was carried out at the 150-160 hour point during the first 400-hour PI schedule, and that, at the time of the accident, the aircraft had accumulated over 311 hours since that last recorded inspection.
12. The operator stated that FMP inspections, which included a check for cracks, were conducted twice daily. These inspections were not documented in the operator's PI records.
13. The operator did not detect any cracked blades in the FMP during the helicopter inspections the night before and the morning of the accident.
14. The FMP installation renders the critical areas of the plate difficult to inspect.
15. The number of cycles as defined by the manufacturer and recorded by the crew had not reached the 8,000 cycle life limit when the FMP failed. However, the number of true cycles experienced by the FMP was almost twice that number.
16. The flight crew was certified and qualified for the flight in accordance with existing regulations.
17. The helicopter's weight and centre of gravity were estimated to have been within prescribed limits.

3.2

Causes

The flexible mounting plate failed in fatigue because the true number of high-load cycles applied to the plate during heli-logging operations were not taken into account in the manufacturer's determination of the service life of the plate. The operator did not detect cracks in the flexible mounting plate during inspections the night before and the morning of the accident.

4.0

SAFETY ACTION

4.1

Action Taken

On 30 October 1987, Aerospatiale Helicopter Corporation (Aerospatiale) recommended a daily inspection of those flexible mounting plates (FMPs) which exceeded 4,000 cycles. Telex number 13253 was issued to all Super Puma operators as an interim safety measure pending further investigation into the causes surrounding this accident. A visual inspection was to be done in accordance with Work Card 63.30.00.601 (WC 63.30) of the Master Servicing Recommendations (MSR). Inspection intervals were not to exceed 10 hours.

In October 1988, the French Airworthiness authorities issued Airworthiness Directive (AD) 88-097-034(B)R2. This AD reduces the service-life of the version of FMP (P/N 330 A28 0100-29), which had been installed on the accident helicopter, from 2,000 to 1,000 hours for all operations except logging operations.

When engaged in logging operations, the AD requires the removal from service of this type of FMP when the plate has been subjected to 4,000 cycles. Any further logging operations shall only be done with a newly designed FMP which features a new blade geometry. This new plate (P/N 332 A38 0106-20) has been assigned a service life limit of 10,000 cycles or 2,500 hours, whichever occurs first. In addition, the AD requires the replacement of other cycle-sensitive drive-train components and reduces the service life limit of others.

Compliance with the AD is to be accomplished in accordance with Aerospatiale's Service Bulletin 01.23 and with the newly established "Supplement for Operation Including Numerous Torque Variations" of the MSR. This AD went into effect on 15 October 1988.

4.2

Further Action Required

4.2.1

Designed Life of the Flexible Mounting Plate

In the arduous environmental conditions of helicopter logging, Aerospatiale determined that the FMP on the Super Puma rotorcraft was subjected to not one, but two low cycle fatigue events for each log transported. These fatigue events, according to the manufacturer, account for the mounting plate fatigue damage.

Despite the determination by the aircraft manufacturer of the number of fatigue events involved in heli-logging operations, the definition of a cycle in the rotorcraft's Maintenance Manual remains unchanged. One cycle, as defined in Aerospatiale's MSR, corresponds to the transport of one external load.

Moreover, Aerospatiale's analysis of probability of plate failure was based on an average slung load weight of 2.5 tons with a maximum load of 3.4 tons. The Canadian Hydra Management operation was reported to involve slung loads as heavy as 5 tons. The marked difference in weights between Aerospatiale's analysis and Hydra Management's actual logging experience would have a significant effect on the stresses experienced by the plate when engaged in Canadian logging operations.

The Transportation Safety Board of Canada (TSB) is concerned that Aerospatiale's definition of a cycle may underestimate the high levels of repeated stresses imposed on the rotorcraft's drive train components when engaged in logging operations. In view of the manufacturer's determination that each log transported results in two low-cycle fatigue events and in view of the heavier slung loads being transported than considered by the manufacturer, the TSB recommends that:

The Department of Transport validate Aerospatiale's analysis of the probability of failure of the newly designed mounting plate (P/N 332 A38 0106-20) when used in Canadian heli-logging operations.

(A91-14)

4.2.2 Flexible Mounting Plate Inspection

The history of prior blade failures on the flexible mounting plate has shown that the fatigue cracks originate at the bottom forward corners of the plate. The limited space between the bottom surface of the plate and the fuselage (nine millimetres) renders visual inspection of the crack initiation sites extremely difficult if not impossible. Fatigue cracks are not easily visible until they have propagated to the upper surface of the plate. Experience has shown that fully cracked blades can remain tightly closed and are difficult to detect visually under ideal environmental and lighting conditions. Moreover, the critical areas of two of the blades are not visible from the top of the fuselage, the only point of inspection access.

The TSB is concerned that the physical location of the flexible mounting plate, when installed in the rotorcraft, renders a visual inspection extremely difficult. Therefore, the effectiveness of any visual inspection can best be described as suspect. Although the Board notes that all but two FMP failures prior to this accident had been detected through the visual inspection procedure recommended by the manufacturer, this accident demonstrates that a visual inspection offers no guarantee that a failed or cracked blade will be detected visually, regardless of the version of the mounting plate. Other inspection methods may be warranted. Therefore, the TSB recommends that:

The Department of Transport assess alternatives for the inspection of Aerospatiale's flexible mounting plate to find a more rigorous procedure.

(A91-15)

This report and the safety action therein have been adopted by the Chairman, J.W. Stants, and Board Members.

APPENDIX A

**WEIGHT AND BALANCE CONDITION ESTIMATED
AT TIME OF ACCIDENT**

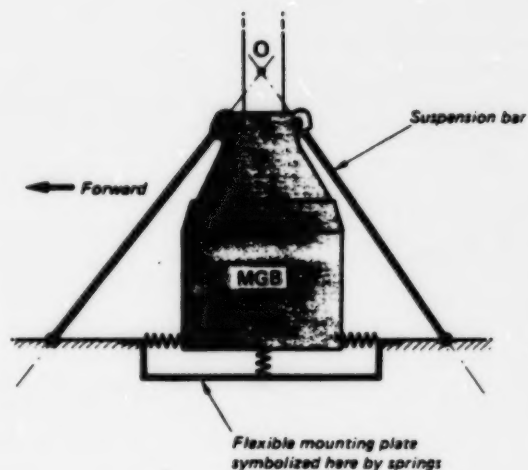
Helicopter empty weight	9,445 lb
Log (estimated by British Columbia Forestry personnel)	7,700 lb
Fuel (estimated remaining)	1,000 lb
Pilot (TC standard summer weight)	182 lb
Co-pilot " "	182 lb
	18,509 lb
Maximum Gross Weight, with sling load	20,615 lb
Centre of Gravity position, as per weight-and-balance form filed with TC	191.45 in.

4.5 - MGB ATTACHMENT AND SUSPENSION

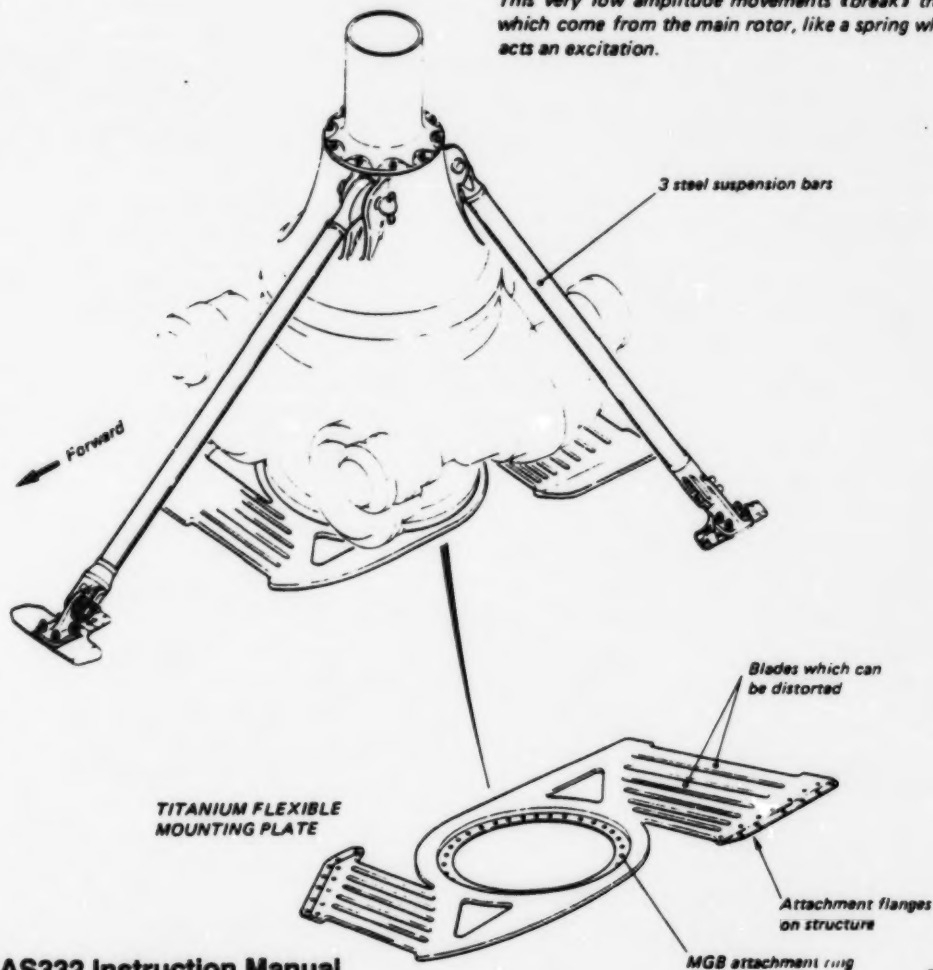
The MGB which supports the rotor mast casing in which the rotor shaft is housed, periodically receives from this casing alternate vertical and horizontal stresses. A rigid MGB attachment on the transmission deck would transmit these vibrations to the entire structure. To prevent this, a flexible suspension, in which the majority of the vibrations is absorbed, is fitted between the MGB and the structure. This type of system is said to filter the vibrations.

The MGB - main rotor assembly is attached to the structure at two levels :

- at the rotor mast by three rigid bars which transmit to the structure :
 - in flight, the rotor lift
 - on the ground, the weight of the rotor and MGB
- at the MGB by a flexible mounting plate, which, located between the bottom of the gearbox and the structure, picks up the main rotor reaction torque and the longitudinal and transverse loads while damping the vibrations.



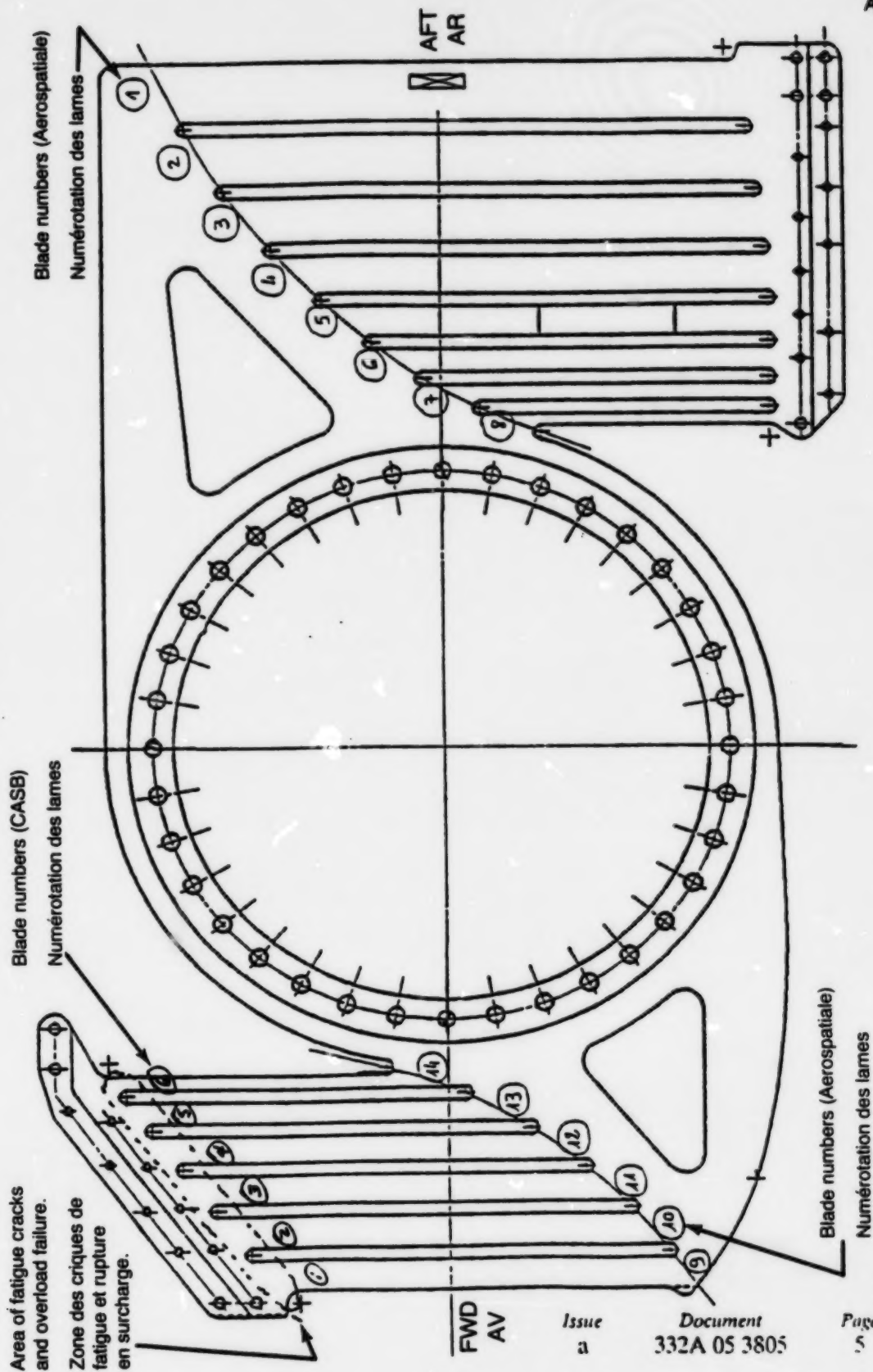
Suspended like a pendulum, the MGB oscillates longitudinally about point O (point of convergence for suspension bars). This very low amplitude movements break the vibrations which come from the main rotor, like a spring which counteracts an excitation.



Excerpt from the AS332 Instruction Manual

B-1

Basic excerpt from Aerospatiale's "Accident Analysis: AS332C - s/n 2012 (Hydra Management)"
Extrait de l'Analyse d'accident - Aerospatiale



Issue
a

Document
332A 05 3805

Page
5



MASTER SERVICING RECOMMENDATIONS

- 5.22 - ADDITIONAL CHECKS - S -

1 SCOPE

The additional checks are primarily concerned with airworthiness requirements, and essentially covers components with short checking intervals.

2 CHECKING INTERVAL (cf. section 5.11) S = 10 hours

These checks are to be carried out every 10 flying hours, or any multiple of 10, as prescribed in the following "Detailed Procedure".

NOTE : The additional check is carried out at the same time as the check "after the last flight of the day" that is the closest to the relevant interval.

3 STANDARD PRECAUTIONS

At each check :

- Refer to the latest Service Bulletins, limitations and intervals (01 & 05).
- Look for :
 - . oil change, lubrication and oil monitoring intervals (5.13),
 - . time limits (5.15),
 - . temporary check dates (5.44).

4 DETAILED PROCEDURE

R

EFFECT	DESCRIPTION	PART NUMBER	INTERVAL
	MAINTENANCE OPERATIONS		
	Additional checks (S)	5.22.00.601	S
	MAIN ROTOR HEAD		
	Frequency adapters		
	- Elastomer visual inspection	62-35-00-601 Para 4.1 //	S
	- Check radial play on large ball joint for a permissible clearance between 0.25 mm and 0.35 mm	62-35-00-603 Para A 62.35.00.601 Para 5.3 // 62.35.00.603 Para A.1	S
	TAIL ROTOR SHAFTING		
	- Bearings	65.10.00.603 3JA	S

Excerpt from AS 332 Maintenance Manual
Extrait du Manuel de maintenance AS 332

5.22

87-20

Page 1

MASTER SERVICING RECOMMENDATIONS

Certain additional operations are required at regular multiples of "S".

EFFECT.	DESCRIPTION	REFERENCE	INTERVAL
	MAINTENANCE OPERATIONS (cont'd)		
	M.G.B (in intensive use : more than 10 cycles per hour of slung load transport)		
	- Readjust the torque loading of bolts MGB to flexible mounting plate	63.20.00.601	Within 2 to 3S
	MAIN ROTOR HEAD		
	Top fairing	62.35.00.601	
	- Check taper support	Para 4.4.1 62.35.00.603 Para L.1	3 S
	OIL COOLING UNIT		
	- Flexible couplings	63.25.00.602 Para JA	3 S
	TAIL ROTOR SHAFTING		
	- Flexible couplings	65.10.00.601 Para JB	3 S
	SUPPORT ASSY		
	- Flexible mounting plate: check attachment points on aircraft structure : absence of cracks.	63.30.00.601 Para 7	4 S (1)
	MAIN ROTOR HEAD		
	Frequency adapters		
	- Check radial play on large ball joint for a permissible clearance between 0 and 0.25 mm	62.35.00.601 Para 5.3 62.35.00.603 Para K	5 S
	- Check small ball-joint on horizontal lug	62.35.00.601 Para 5.3 62.35.00.603 Para K	5 S
	OIL COOLING UNIT		
	- Supports for fan and oil cooler - ducts	63.25.00.602 Para JB	5 S
	TAIL ROTOR		
	- TRH pitch-change bearing stack : check bearing rotational torque	64.20.00.604 Para 3.6 // 64.20.00.603 Para 3.A1	5 S
	POWER PLANT INSTALLATION		
	- Check torque loading of engine-to-MGB attachment bolts	71.00.00.603 Para 2	5 S

(1) from 1000 operating hours or 4000 cycles.
Excerpt from AS 332 Maintenance Manual
Extrait du Manuel de maintenance AS 332332

MASTER SERVICING RECOMMENDATIONS

R

EFFECT.	DESCRIPTION	REFERENCE	INTERVAL
	TAIL ROTOR - Check pitch-change links for play and binding	64.20.00.603 Para 3B // 64.20.00.602 Para 3	10 S
	DOORS - Side plug doors special check	52.11.01.601 Para 7	10 S
	OIL COOLING UNIT - Fan rotor - Visually check the fan blades	63.25.00.602 Para 3F	20 S
	LUBRICATION - TRH hinge	64.20.00.301	2 S to 3 S (1)
	- MRH swashplate	62.35.00.603 Para D // 62.35.00.601	20 S
	- MRH blade horn	62.35.00.603 Para D // 62.35.00.601	20 S
	- Rotating and non-rotating scissors bolts	62.35.00.603 Para D // 62.35.00.601	20 S
	- Swashplate trunnions	62.35.00.603 Para D // 62.35.00.601	20 S

R

(1) Recommended at 2 S

Excerpt from AS 332 Maintenance Manual
Extrait du Manuel de maintenance AS 332

5.22

MAINTENANCE

MAIN GEAR BOX SUPPORT Suspension bars and flexible mounting plate checking	332	63.30.00.601 81-48 Page :
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1 EQUIPMENT REQUIRED

1.1 Special tools

- None.

1.2 Materials

- Baitane.

1.3 Routine replacement parts

- None.

1.4 Applicable documents

- None.

2 PRELIMINARY STEPS

- Open :
 - . sliding cowling
 - . engine hinged servicing cowlings.
- Remove forward bar protective cover.

3 SUSPENSION BARS (9)

- Check :
 - . tube condition, check for scoring - distortion - cracks - corrosion.
- IMMEDIATELY WITHDRAW FROM SERVICE ANY BAR WHICH HAS SCORING OR DENTS :
 - . deeper than 0,4 mm
 - . less than 50 mm one from another
 - . less than 50 mm from welds (8).

3.1 Bar attachment fitting on MHR casing

- Check :
 - . condition of yokes on casing : check for cracks - corrosion
 - . condition of bolts (6) : check for pitting - corrosion - presence of lock pins (7).

3.2 Bar attachment fittings on transmission deck

- Check :
 - . condition - security - locking of fittings (1-2) on transmission deck
 - . check for cracks - corrosion.

Excerpt from AS 332 Maintenance Manual
Extrait du Manuel de maintenance AS 332

MAINTENANCE

332

63.30.00.601

86-30

Page 2

4 BAR ATTACHMENT FITTINGS ON TRANSMISSION DECK

Check :

- condition, security and locking of fittings on transmission deck : check for cracks - corrosion.
- with an open-ended spanner by moving the nuts check bolts are not broken.
- condition and security of support plates (3) in visible area around fittings : check for cracks - corrosion - loosening of rivets.

Only if safetying is defective :

Torque nuts on forward fitting (1) and rear fittings (2) to required load.

5 SUSPENSION BAR ATTACHMENT BOLTS (6)

Check bolt condition : check for pitting, corrosion, flaking.

6 LOCK PINS

Condition of pins (7).

7 FLEXIBLE MOUNTING PLATE ATTACHMENT AREAS (DETAIL H)

Crack detect the hatched areas shown in detail H. Any crack detect requires the flexible mounting plate to be removed and discarded.

8 CHECKING THE FLEXIBLE MOUNTING PLATE

8.1 From inside cabin, check

- attachment nuts tightening (red paint marks)
- torque of screws (3-4) securing flexible mounting plate to transmission deck (if necessary).

8.2 On transmission deck

- Check clearance between mounting plate and structure : over 0.9 mm (taking particular care to the forward LH area of mounting plate)
- Check flexible mounting plate (5) condition : check for cracks, scoring, corrosion or distortion :
 - . cracks at plate attachment screw heads
 - . scoring.

CAUTION : ANY CRACK OR SCORING SITUATED WITHIN THE HATCHED AREA OF DETAIL H, FIGURE 2 REQUIRES THE FLEXIBLE MOUNTING PLATE TO BE REMOVED AND DISCARDED.

- Blend out scoring complying with the following :
 - . maximum depth of rectification 0.3 mm
 - . two rectifications must not be adjacent.
 - . blend out radius must be at least 50 times the depth of the rectification

- A flexible mounting plate showing a more than 0.3 mm deep scratch in any area of its faces shall be removed from service. R

Excerpt from AS 332 Maintenance Manual
Extrait du Manuel de Maintenance AS 332

MAINTENANCE

332

63.30.00.601

86-30

Page 3

8.3 In case of removal of the flexible mounting plate check it for condition as per previous paragraph (face against transmission deck) and blend out complying with procedure.

8.4 Precautions

- When scraping and polishing, use non-mechanical equipment so as to smooth without burning. Surface roughness after polishing: 1.6 microns R for all strips and 3.2 microns for all other surfaces. R
- Any blending out operation must be terminated by sanding with a 400 grit paper.
- Protective treatment is not required after blending out.

9 FINAL STEPS

- Install forward suspension bar protective cover.
- If necessary, re-new sealing beads around fittings on transmission deck.
- Close :
 - . hinged servicing cowlings.
 - . sliding cowlings.

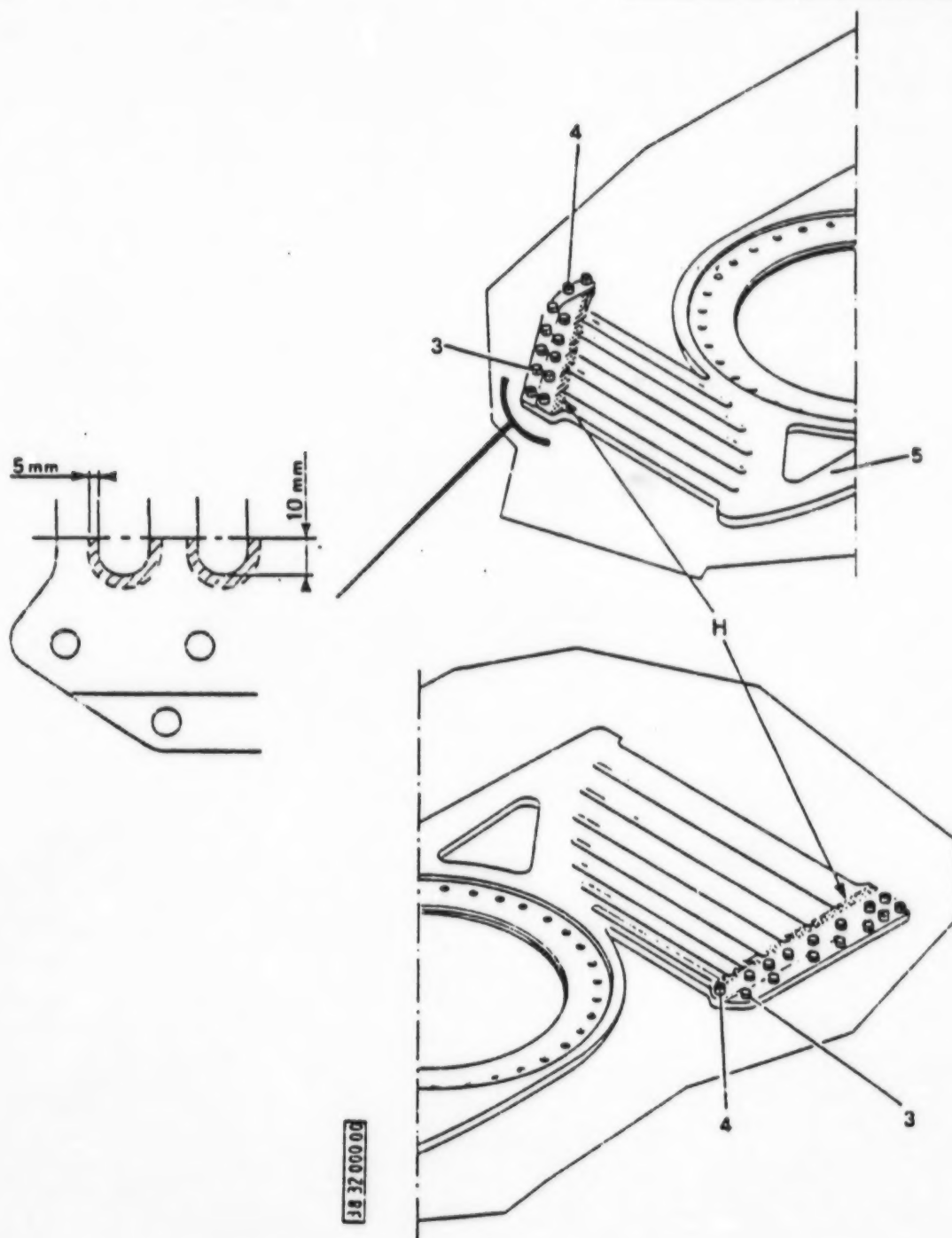
Excerpt from AS 332 Maintenance Manual
Extrait du Manuel de maintenance AS 332

332

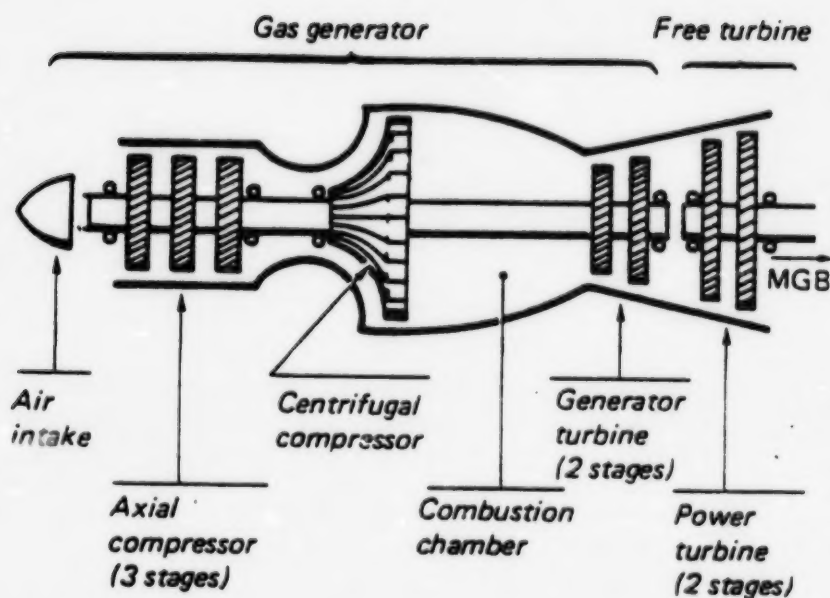
63.30.00.601

85-38

Fig. 2



Excerpt from AS332 Maintenance Manual
Extrait du manuel de maintenance



MAKILA Engine Schematic Diagram

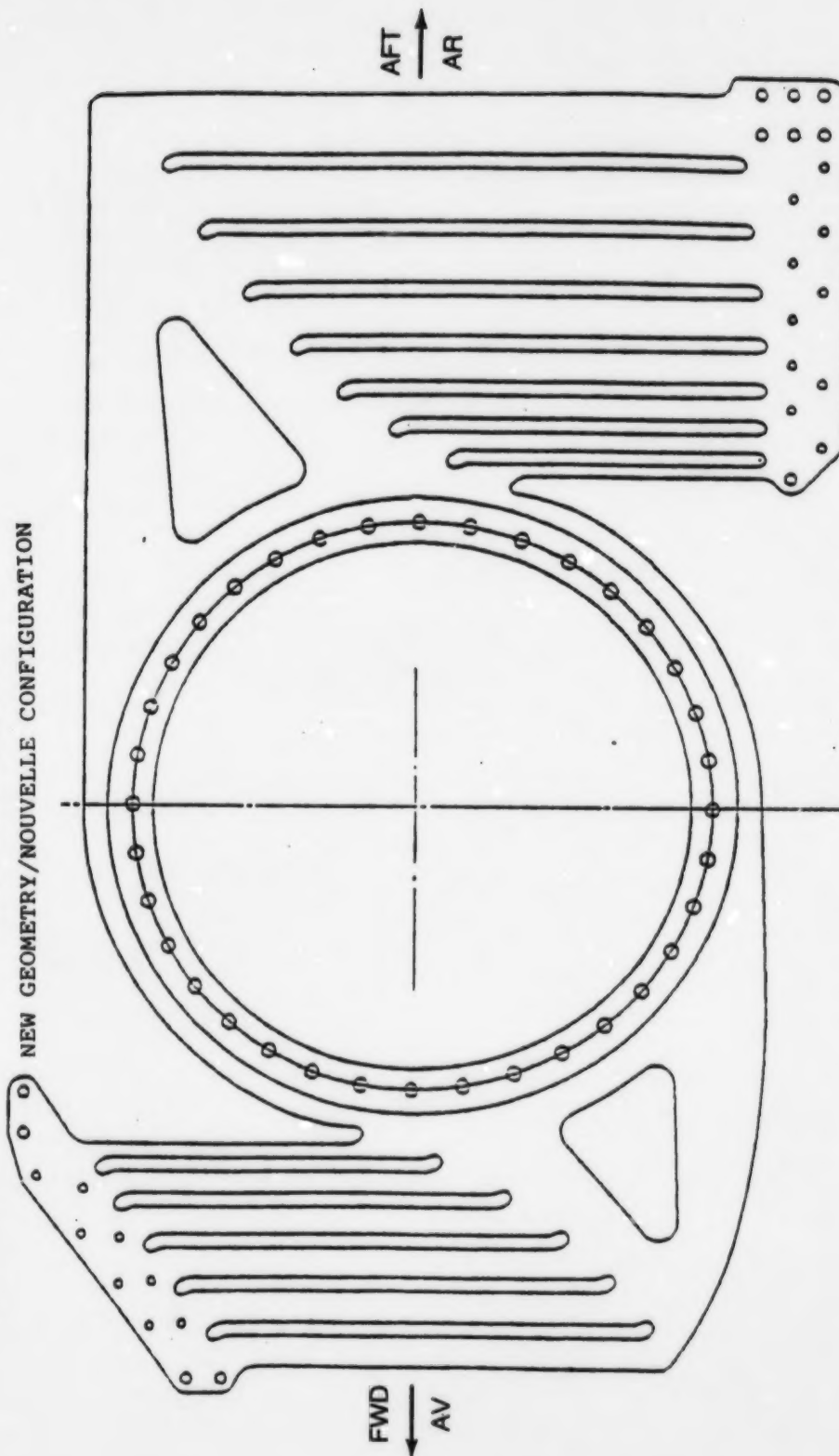
Excerpt from Aerospatiale AS 332 Flight Manual

Extrait du Aerospatiale AS 332 Flight Manual

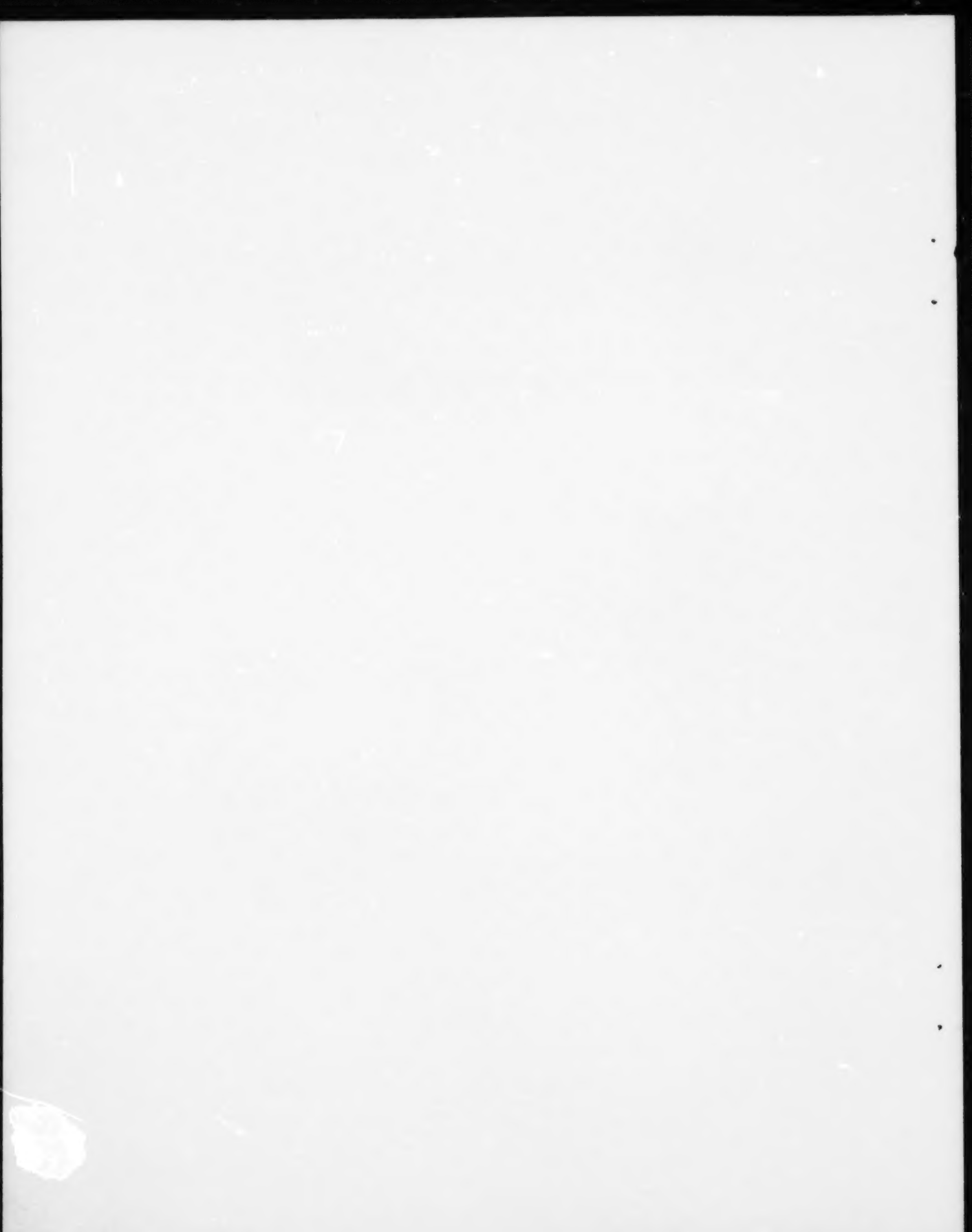
**Excerpt from Aerospace Information
Extrait de l'information Aérospatiale**

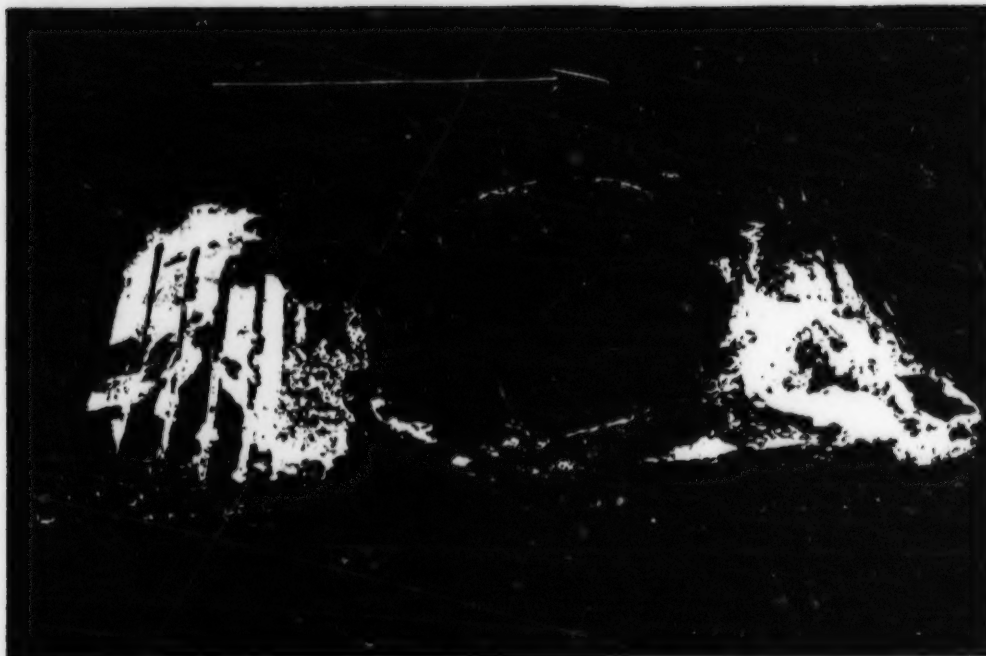
AS332 FLEXIBLE MOUNTING PLATE
AS332 PLATINE ASSOUPLIE

NEW GEOMETRY/NOUVELLE CONFIGURATION

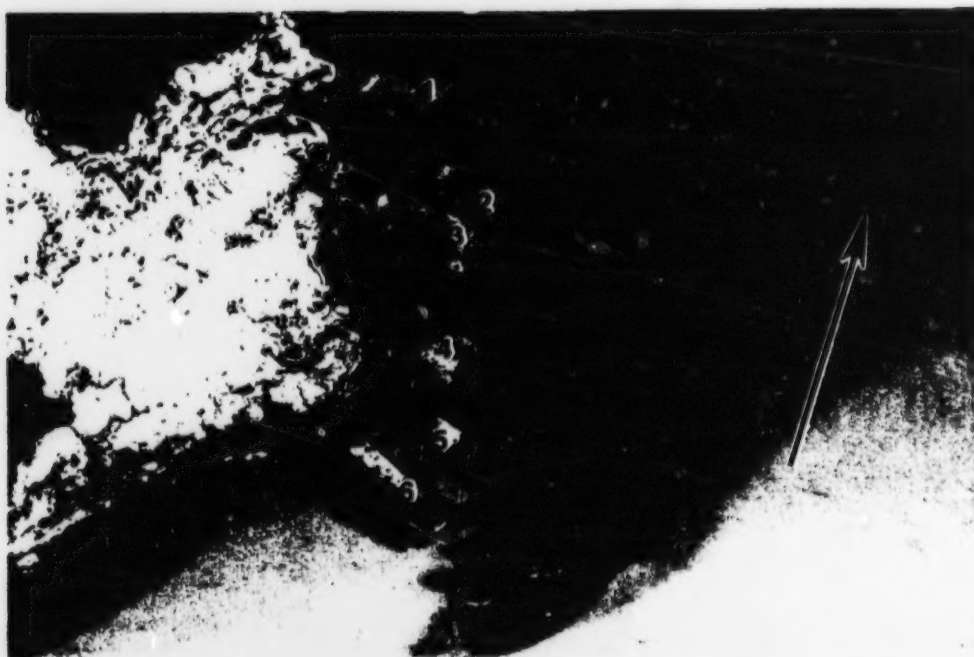


Optimizing Flexible Struts' Bending Radius
Optimisation: Rayons des fentes de la platine assouplie





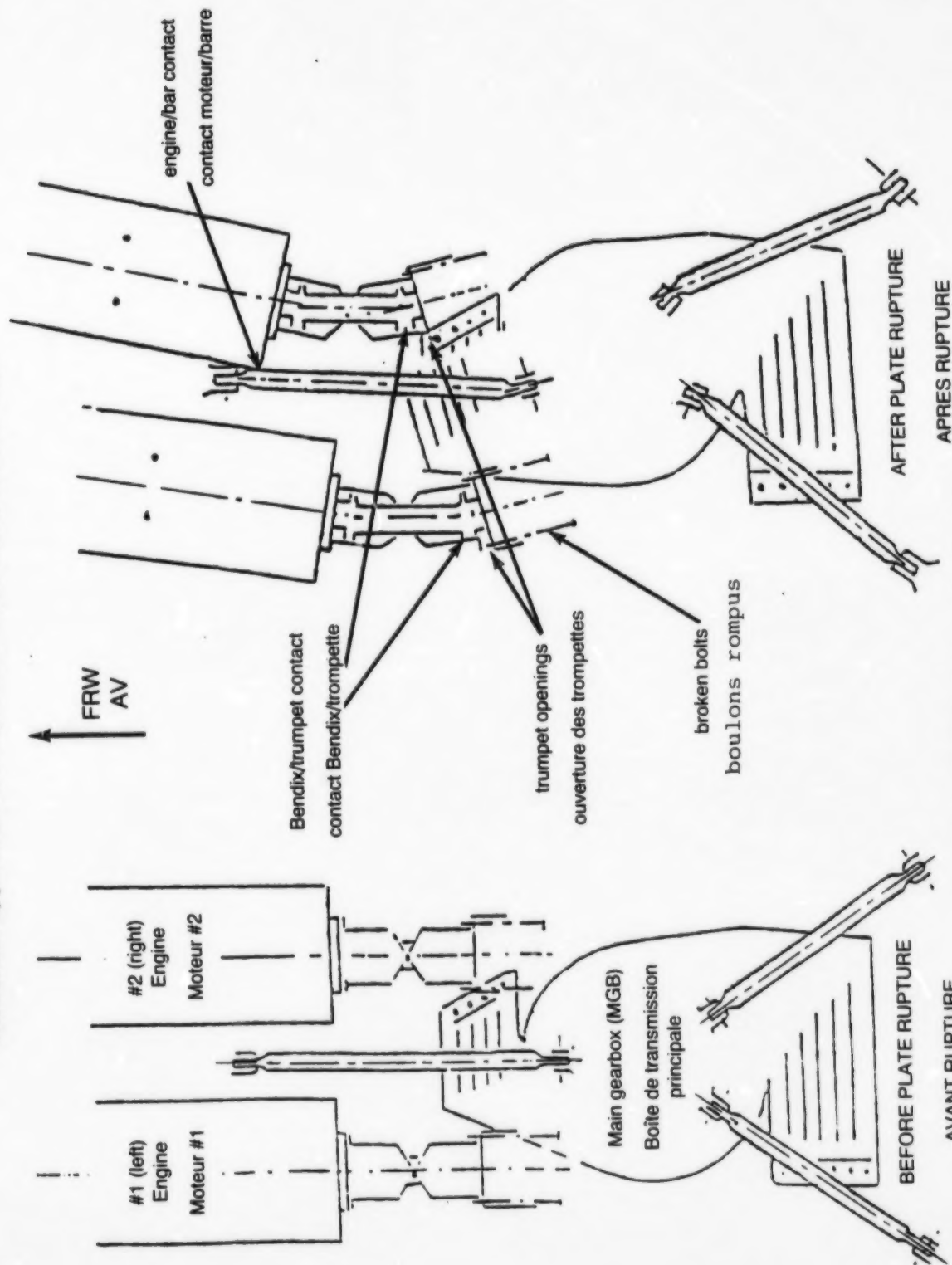
TRANSMISSION FLEXIBLE MOUNTING PLATE AS RECOVERED
FROM THE ACCIDENT SITE.



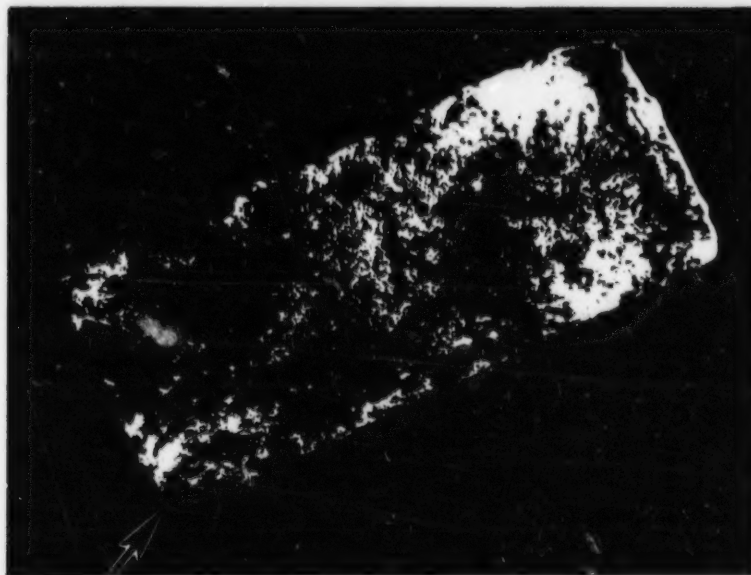
FLEXIBLE MOUNTING PLATE SHOWING SEPARATION OF THE
FORWARD ATTACHMENT SECTION THROUGH THE SIX TUNING
BLADES.

Excerpt from CASB Engineering Laboratory Report 227/87.

Excerpt from Aerospatiale Report MB/MG H/AV, TPSP n° 3463
Extrait du rapport de l'Aerospatiale MB/MG H/AV, TPSP n° 3463



Comparison of MGB/Engine Alignments
Comparaison des alignements B.T.P./moteur



- BLADE FRACTURE #3 SHOWS THE MOST DISTINCTIVE FATIGUE FRACTURE FEATURES OF MACROSCOPIC "BEACH MARKS" EMANATING FROM AN ORIGIN AT THE CORNER ON THE BLADE LOWER SURFACE (ARROW).
- LA SURFACE FRACTURÉE DE LA LAME N° 3 MONTRE LES CARACTÉRISTIQUES MACROSCOPIQUES LES PLUS DISTINCTIVES DE RUPTURE PAR FATIGUE AYANT POUR ORIGINE LE COIN DE LA SURFACE INFÉRIEURE DE LA LAME (FLÈCHE).



- BLADE FRACTURE #4 ALSO SHOWS FLAT FRACTURE INITIATING AT THE CORNER ON THE BLADE LOWER SURFACE (ARROW).
- LA SURFACE FRACTURÉE DE LA LAME N° 4 MONTRE ÉGALEMENT UNE RUPTURE PLATE AYANT POUR ORIGINE LE COIN DE LA SURFACE INFÉRIEURE DE LA LAME (FLÈCHE).

H-1

APPENDIX J

LIST OF LABORATORY REPORTS

The following laboratory reports were completed:

- LP 214/87 - Turbine Disc Failure;
- LP 227/87 - Transmission Mounting Plate Failure;
- LP 228/87 - Engine Transmission Examination;
- LP 229/87 - Bendix Coupling Failure; and
- LP 230/87 - Technical Summary Report.

These reports are available upon request from the
Transportation Safety Board of Canada.

APPENDIX K

GLOSSARY

AD	Airworthiness Directive
AME	aircraft maintenance engineer
asl	above sea level
CVR	cockpit voice recorder
DGAC	Direction Generale de l'Aviation Civile
FDR	flight data recorder
FMP	flexible mounting plate
fpm	feet per minute
hr	hour(s)
lat	latitude
lb	pound(s)
long	longitude
MGB	main gearbox
MSR	Master Servicing Recommendations
PDT	Pacific daylight time
PI	progressive inspection
P/N	part number
rpm	revolutions per minute
TC	Transport Canada
TSB	Transportation Safety Board of Canada
UTC	Coordinated Universal Time
WC	work card
°	degree(s)
'	minute(s)